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AERIAL MAPPING IN MALARIA CONTROL[1]

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For a number of years the Tennessee Valley Authority has employed aerial photographs in the preparation of many types of maps for use in its reservoir project activities and in the Valley-wide planimetric and topographic mapping program. The aerial photography has been supplied by contract and the map processing has largely been done by TVA personnel. Fig. 1 is an example of the topographic maps which are being prepared jointly by USGS and TVA covering the entire Tennessee River Watershed. This type map is prepared from aerial photographs by stereophotogrammetric method. Approximately one-half of the Tennessee River Watershed has been mapped to date in this manner.

The exigencies during World War II brought out the utility of aerial photography for developing topography maps needed in planning permanent malaria control works in certain of the previously impounded reservoirs of the lower part of the Tennessee River. The Authority's initial use of engineering works in the form of diking and dewatering and deepening or filling to permanently eliminate shallow mosquito breeding areas was reported on by Bishop and Gartrell (1944) and Gartrell (1945). The permanent malaria control works in the Kentucky Reservoir were planned and constructed prior to impoundage. The original mapping program for this reservoir provided sufficient topography information for the initial studies of feasibility and cost of the engineering work. Some additional contouring by plane table was required in the final stages of planning.

The success of the shoreline improvement program in the Kentucky Reservoir led to an exploration of the possibility of utilizing permanent malaria control measures in five other previously impounded main stream reservoirs. Adequate planning called for additional topography, principally one-foot contours, in the shallow mosquito problem areas of the reservoirs, since it had not been provided on the original reservoir maps. In Pickwick, one of the smallest of these reservoirs, conventional plane table strip topography showing one-foot contours on a scale of 1 inch = 200 feet was obtained in selected shoreline and channel areas during the fall of 1943. Work of this type costs on an average of about $10.00 per acre and it was seen that the use of similar methods for obtaining additional topography in the larger remaining reservoirs would entail a very considerable allotment of funds even if survey parties

[1] Presented at XXIX annual meeting of the National Malaria Society, Miami, Florida, November 5–7, 1946.

could have been recruited at that time. The situation led to an exploration of the possibility of photographing the areas from the air, with a view of utilizing water lines and possibly vegetation bands to obtain the necessary contours. Some work of this type was known to have been done previously by others in connection with preparation of reservoir flowage topography.

The first experimental work to obtain reservoir shoreline contours by the Authority was done in the fall of 1944 with a simple 12-exposure $3\frac{1}{4}$ inch x $4\frac{1}{4}$ inch pack camera mounted in a cub airplane which permitted taking a strip of overlapping

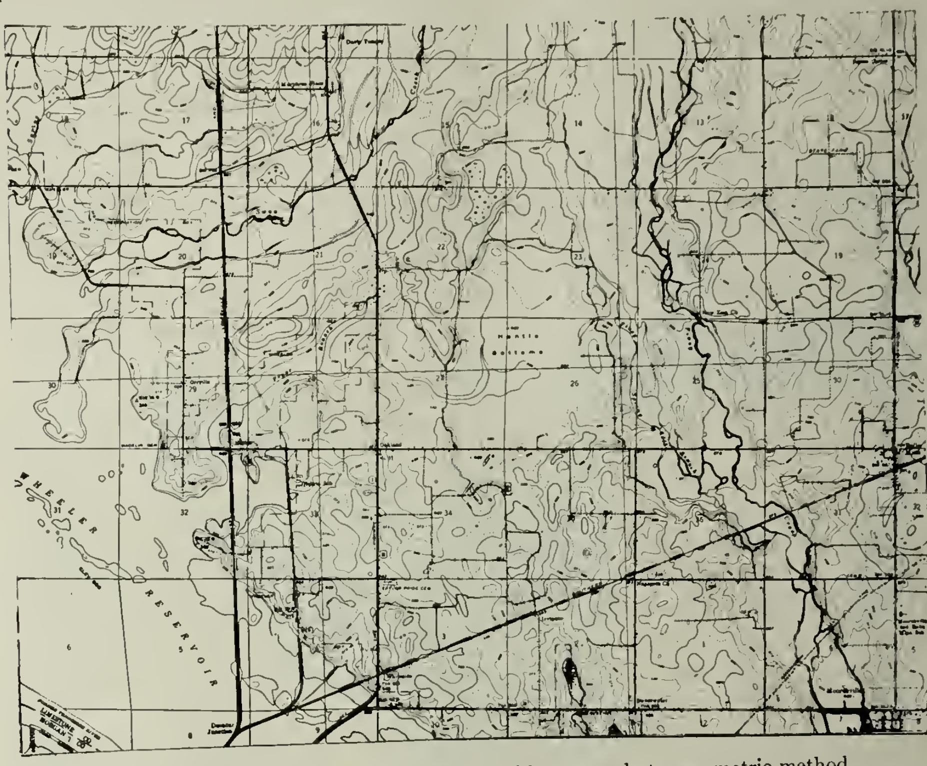

FIG. 1. Section of topographic map compiled by stereophotogrammetric method

pictures. This initial work proved so promising that a Folmer K-5 aerial camera with $8\frac{1}{4}$ inch focal length taking 7 inch x 9 inch pictures was purchased, and a definite topography mapping program initiated during the winter of 1944–45. The original camera mounting was in the cub airplane, but later the Authority purchased a BT-17, 450 H.P. Vultee airplane for utility service which has been used largely in the mapping work (Fig. 2). The Authority's contract aerial mapping service was not considered practical for this particular work, since so much time would have been lost "standing by" for favorable weather and lake elevations. The adopted plan was rather to utilize Authority personnel and facilities regularly employed on its other mapping and flying activities, thus minimizing the standby expense.

Photographs of selected problem areas in four large reservoirs were taken on days

when the weather was favorable and the reservoir pool was at the desired elevation. The Authority's River Control Section of the Water Control Planning Department provided valuable assistance in the forecast of reservoir stages, and in some instances regulated stream flow to obtain specified lake elevations on days of favorable weather. In order to secure approximately one-foot contour intervals it was necessary to photograph each area as many times as there were contours desired, and when the water had reached the elevation specified.

After the photographs were obtained, they were ratioed to a common scale and water level contours superimposed. The best series of pictures, usually the set taken at the lowest water level, were used as a base upon which contours from the other sets of photographs were added through the use of an overhead reflecting projector. Descriptive data and titles were then added to the base picture. The final step was to photograph this base picture for making reproduction. Fig. 3 shows one of these

Fig. 2. Vultee airplane BT-17, 450 H.P. equipped for aerial reconnaissance, photography, and airplane larviciding.

finished photo-topography maps. Fig. 4 is a reproduction of a photograph upon which has been superimposed a cut and fill layout.

Where preliminary plans indicated the cut and fill procedure, maps were required showing one-foot contours in the upper 3-foot zones of the mosquito problem areas. Where diking and dewatering was indicated, larger areas were usually involved requiring maps of less detail but contours extending down 5 or 6 feet below the normal reservoir level. The cut and fill procedure calls for deepening the lower one-half of the marginal growth invasion zone (normally about 2 feet in TVA main-stream reservoirs), with the excavated earth being placed in the upper one-half to raise the ground level above the normal lake level. A steep shoreline is thus effected which offers little or no mosquito potential. Diking and dewatering involves diking around large shallow mosquito breeding areas and constructing interior drainage systems and pump stations to dewater the areas. Detailed topography maps were required for planning and estimating the cost of these permanent works.

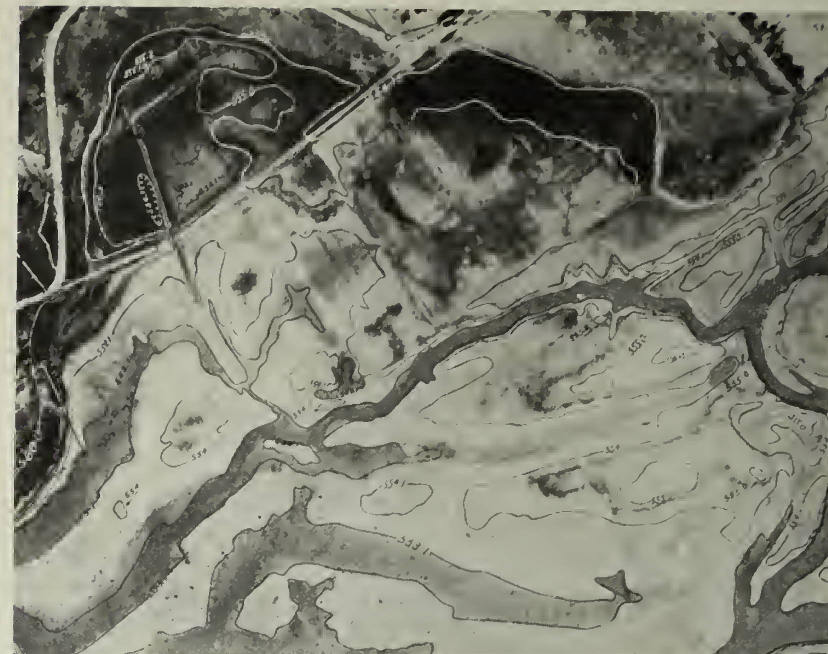

FIG. 3. Section of completed aerial topographic mosaics showing marginal mosquito problem areas.

FIG. 4. Section of aerial topographic mosaic showing construction plan for eliminating mosquito problem area through deepening and filling the upper 2-foot marginal zone.

The aerial mapping work progressed steadily during 1945 and 1946 and the original program is now practically completed. Topographic maps of this type, scale

1 inch = 200 feet or 1 inch = 500 feet, have been obtained in 88 separate areas of 4 large reservoirs. In order to obtain the necessary contours, most of the areas were photographed 3 or 4 times. The work required a total of 2250 separate 7 inch x 9 inch photographs. Adequate coverage and stereoscopic contour delineation called for a 50 per cent overlap of the pictures. The photographs were taken to give a contact print at a scale of approximately 1 inch = 500 feet which necessitated flying at about 4,000 feet above the average ground elevation. The 1 inch = 500 feet contact print scale was desirable for the detail it furnished and also because it could be satisfactorily enlarged to a 1 inch = 200 feet base picture for the topographic map. It is estimated that 120,000 acres were embraced by the maps, 15 per cent or 18,000 acres of which were contoured.

The taking of the photographs extended over the period from March 1945 to September 1946. During this time, photographs were taken on 25 separate days. Approximately 90 hours of flying time were required, of which 40 per cent was spent taking photographs and the remainder in ferrying to and from the areas in the several reservoirs. Although the taking of photographs extended over 18 months, it could have been accomplished in one season extending from the spring filling of the reservoirs to the fall drawdown of lake levels. However, this would have required especially constant alertness so as to utilize every opportunity of favorable weather and desired reservoir water levels.

The following table lists the items of work required and the estimated costs for one acre of actual contoured map.

Item		*Cost for 1 acre*
1. *Preliminary work*		
Preparation of flight maps and setting temporary water elevation gauges near mosquito problem areas to be photographed	$.06	$ .06
2. *Photography*		
Airplane charges allowing 0.3 min. per acre flying time at $30.00 per hour	.15	
Photographer's time allowing 50 per cent standby at 10 min. per acre	.04	
Film developing, prints and indexing	.14	
Assistant Photographer and gauge reading	.03	
3. *Preparation of Maps*		.36
Scale checking photographs, delineation of contour lines, spot field checking on delineation of contour lines, projecting contours to enlargements, and preparation of map tables	.55	
		.55
4. *Reproduction*		
Making negatives and supplying one photograph and 4 blue line work prints	.10	
		.10
5. *Overhead*		
Planning, supervision, contingencies	.11	
		.11
Total Cost of Mapping Per Acre		$1.18

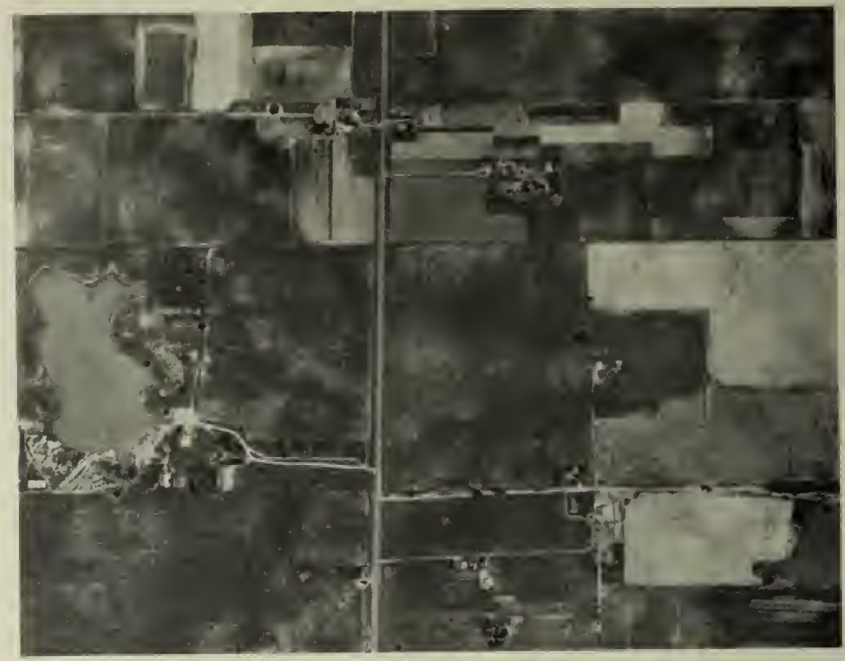

FIG. 5. Typical photograph used in locating ponded areas outside TVA reservoirs.

FIG. 6. A typical aerial photograph used to record the effect of 2,4-D on lotus growths.

The total estimated cost of preparing detailed topographic coverage of the 18,000 acres proposed for shoreline improvement in the 4 large main stream reservoirs was

about $1.20 per acre, which seems very reasonable when compared to the $10 per acre cost required for obtaining topography by conventional plane table method in the Pickwick Reservoir. The photograph maps are superior to conventional plane table maps in that they show stumps, trees, brush, and other details which are not readily procured by plane table surveys. Of course, the very low cost of the aerial photography mapping is attributed, in part, to the manner of making charges against the job for facilities and personnel only when actual work was being performed. Facilities and personnel were employed on other regular work when weather conditions or lake-elevations were unsuitable for the aerial mapping.

The aerial photography service of the Authority has been put to numerous other uses in malaria control. For instance, Colbert County, Alabama, passed a malaria control tax to provide funds for applying malaria control measures in a section of the county containing numerous lime sink ponds where drainage is expected to constitute the principal approach. A portion of the district lies within mosquito flight range of one of the Authority's main river reservoirs, Lake Wilson, hence the Authority has an especial interest in the local malaria control program. In view of this interest, the Authority photographed the district this summer to provide the county with current data which will be of value in planning the drainage work scheduled to begin this fall. The pictures were taken at an elevation of about 8000 feet above the average ground elevation to produce a map scale of 1 inch = 1000 feet. Valuable information which could not be provided in such detail by ground reconnaissance can be readily taken from these photographs. Fig. 5 shows a section of the ponded area in Colbert County photographed in this manner. The aerial pictures covered 213 square miles of the county. The photographing was done in one day, requiring only 5 hours flying time, and the direct field cost, including flying, negatives, and one photograph print was $2.24 per square mile. Additional prints can be provided for only $0.28 per square mile. It is seen from these figures that even a superficial reconnaissance from the ground would cost more than aerial photographs, and in general would not provide as much useful information.

Aerial maps have been used for planning and estimating pre-impoundage reservoir preparation and post-impoundage maintenance operation for malaria control in Authority reservoirs. Such maps have been especially useful in locating and estimating reservoir clearing and marginal growth removal.

The Authority has also utilized aerial photography to quickly obtain a base map for planning special malaria control drainage work in the Kentucky Reservoir. Other uses have developed for photographing special marginal growth situations from the air, as well as progress on growth control studies, and it is apparent that aerial mapping using color photography will eventually develop into a useful practice. Fig. 6 shows the effect of herbicidal treatment on lotus in the Wheeler Reservoir.

The Authority's Maps and Surveys Division handled the mapping work discussed herein, with Messrs. Russell Dittmer and Jim Carrigan doing the photographing. The flying was done principally by Mr. H. B. Seaton, Chief Dusting Pilot of the Authority's Aviation Section. Messrs. E. A. Philen and F. W. Thomas represented the Authority's Health and Safety Department, which is responsible for developing, planning and appraising the malaria control programs on the impoundages.

SUMMARY

(1) The Tennessee Valley Authority has made extensive use of aerial photography in its general mapping program.

(2) The shortage of technical personnel and relatively high cost prevented use of conventional plane table survey methods to obtain contoured maps required for planning and estimating permanent malaria control works in the mosquito problem flats of four previously impounded main stream reservoirs of the Tennessee River Development.

(3) The necessary maps were obtained by taking aerial pictures of the areas at different lake elevations to obtain contours at approximately 1-foot intervals over a range of 3–6 feet below normal lake elevations during the period March 1945–September 1946.

(4) The estimated cost of obtaining the aerial topography maps at $1.18 per acre compares most favorably with the estimated cost of obtaining such maps by conventional plane table method at $10.00 per acre.

(5) In addition, the Authority has used aerial photography to obtain maps needed in planning and estimating pre-impoundage reservoir preparation and post-impoundage marginal growth control work and malaria control drainage.

RESUMEN

(1) The Tennessee Valley Authority ha usado extensamente la fotografía aérea en su programa general de levantamiento de mapas.

(2) La escasez de personal técnico y su alto costo relativo hicieron imposible el empleo de los sistemas topográficos convencionales en el levantamiento de los mapas acotados necesarios para proyectar y presupuestar obras permanentes de control antimalárico en las laderas con problema de mosquitos, adyacentes a cuatro embalses previamente construídos en ríos principales de The Tennessee River Development.

(3) Los mapas necesarios fueron levantados tomando fotografías de las áreas del lago a diferentes niveles, para obtener curvas de nivel a un pie de intervalo aproximadamente, hasta 3 a 6 pies por debajo del nivel normal de las aguas, durante el período de Marzo/45–Septiembre/46.

(4) El costo presupuestado de $1.18 por acre del levantamiento aerofotográfico de mapas puede compararse ventajosamente con el de $10.00 por acre presupuestado para el levantamiento por sistemas topográficos convencionales.

(5) Además, the Authority ha usado la aerofotografía en el levantamiento de los mapas necesarios para planear y presupuestar la preparación del sitio del embalse y el control del crecimiento de la vegetación marginal y los drenajes antimaláricos después de construído el mismo.

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POTENTIALITIES OF TRANSPORTATION OF EXOTIC ANOPHELINES BY AIRPLANE[1]

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The United States, like other countries of the World, have had a number of costly experiences as a result of the accidental importation of exotic insect pests through commerce. The European corn borer, cotton boll weevil, Mediterranean fruit fly, gypsy and brown-tail moths, and Japanese beetle are some of the more notorious examples of imported species that have had far-reaching effects on our national economy. Hundreds of other less dramatically noxious insect aliens have gained ingress. How great is the danger of similar introduction and establishment of insect vectors of disease, especially in view of our ever-increasing and more rapid air traffic with other countries? It is the purpose of this report to consider these questions with regard to the potential danger of importation of exotic anophelines into the United States by airplane and its possible effect on our malaria problems.

Attention to this possibility has been heightened in recent years by the unfortunate experiences of Brazil in 1930-40 and Egypt in 1942-44 with the insidious infiltration of *Anopheles gambiae* from tropical Africa, a most dangerous vector which caused unusually severe epidemics of malaria. The United States became, in the past, unwitting—and, in retrospect, unwilling—hosts of exotic insects detrimental to health and comfort. Besides the yellow fever mosquito and the Indian rat flea, such unwanted guests, which probably long ago made their homes here, include cockroaches, bedbugs, and the house fly. While malaria mosquitoes are the subject of this report, they form only part of the general problem of accidental importation of medically important arthropods and the diseases they transmit. Increasing knowledge of the epidemic virus-encephalitides, for example, indicates that they, also, may be spread by mosquitoes, and foreign types seem well adapted to gain a foothold in the United States if the viruses should be introduced through the importation of infected man, animals, or vectors. It is not sufficient to center quarantine attention upon mosquitoes that are potential vectors of yellow fever and malaria. The so-called "pest" species have greater potentialities than is generally realized, so it is well that they, too, are equally guarded against by our protective measures.

HISTORICAL REVIEW

The problem of transportation of diseases and disease-vectors was recognized early in the development of international aeronautical commerce and travel. The mosquito-borne disease yellow fever, with its long and dramatic history of seaport epidemics and spread through surface commerce, was naturally a first cause of

[1] Report of the Committee on Entomology, given at the 29th annual meeting of the National Malaria Society, Miami, Fla., Nov. 5–7, 1946.

concern in this regard. Fear of this and other diseases prompted quarantine officials of the International Office of Public Hygiene in Paris to draw up a proposed International Convention for the Sanitary Control of Aerial Navigation in May, 1930, under the 1919 convention relating to the regulation of aerial navigation. In April, 1934, the United States signed this "International Sanitary Convention for Aerial Navigation of April 12, 1933" and it soon thereafter became effective as a code of aeronautical quarantine procedure (Ann. Rept. U.S.P.H.S., 1934). It was modified and amended by the International Sanitary Convention for Aerial Navigation of 1944, in force since January 15, 1945 (Souza, 1945). In this document Articles 38 and 51 refer to measures against yellow-fever vectors: mosquito-control and mosquito-proofing of dwellings on "sanitary aerodromes" in areas where yellow fever is endemic and airports exposed to risk of its introduction; the disinsectization of planes at each aerodrome within yellow-fever areas (particularly the last port of departure); sanitary aerodromes and airplane disinsectization at the first port of call where yellow fever does not exist but could develop; and inspection and disinsectization of airplanes in regions not permitting the development of yellow fever. Article 54, an amendment of 1944, reads: "In view of the special risk of conveying insect vectors of malaria and other diseases by aircraft on international flight, all such aircraft leaving affected areas will be disinsected . . . further disinsectization of the aircraft on or before arrival may be required if there is reason to suspect the importance of insect vectors."

In the United States, the Quarantine Act of 1893 was extended to cover aircraft in 1926 (Magath, 1945a). Efforts of the Public Health Service to evaluate and deal with the danger of importing mosquito vectors are recorded in its Annual Reports. They include the following: Experiments on the transportation of *Aëdes aegypti* in planes (1931–32; see below). Development of insecticides for aircraft (1934, 1936). Required inspection and disinsectization of aircraft both upon departure for and arrival at Honolulu, and encouragement of airplane operators to screen planes and use sprays during flight, in order to prevent the introduction of anophelines into malaria-free Hawaii (1936). Vaccination of aircraft personnel, surveillance of exposed travelers, disinsectization of aircraft, and mosquito eradication around airports to meet the hazard of yellow-fever importation, emphasized by the discovery of the "jungle" type of this disease in South America (1937, 1938). Training programs for inspectors and emergency *aegypti* control units at air terminals in the southern United States, and the establishment of aircraft disinsectization bases in Trinidad, Venezuela, and Colombia, and inspection bases in Jamaica and Haiti (1939–41). Fear of insect-importation was increased by the *gambiae*-malaria epidemic suffered by Brazil in 1940 and the advent of war, which suddenly extended air traffic to all parts of the world. Additional entomologists (seven assigned to the Foreign Quarantine Division by the Office of Malaria Control in War Areas) were stationed at airports of entry. While military flights were permitted without quarantine restrictions between the United States and certain designated areas of the Caribbean region, the Canal Zone, Bahamas, Virgin Islands, Alaska, and Canada, all aircraft having contact with other areas were subject to inspection and treatment. All commercial aircraft entering the United States, south of 40° N. latitude, from

South America, north of 30° S. latitude, and from Africa were required to be disinsected without preliminary inspection immediately after disembarkation of passengers (1941–42). To care for the increase in planes from Africa, an air-quarantine station was established at Washington, D. C. (1942–1943). In 1943–44 air traffic increased 61.8 per cent, and entomological surveys were conducted at Brownsville, Fort Worth, Miami, and New Orleans airports. The value of such surveillance was indicated by the discovery of a larval specimen of *Anopheles albimanus* by an Army entomologist at Boca Raton, Florida, in May, probably originating from a gravid female brought by a plane from Puerto Rico. In the same year the effectiveness of residual DDT in aircraft was investigated at Miami. Detailed records of insects recovered from arriving aircraft were initiated, and these have been continued during the ensuing years. In 1944–45 there was a further increase of 77 per cent in airplane arrivals, eight entomologists were employed at air quarantine ports, and for the first time an African mosquito, *Anopheles pharoensis* (one dead specimen), was found on an incoming plane at Miami. The Annual Report for 1945 included the first listing of mosquitoes recovered from aircraft at quarantine stations (a practice which ought to be continued).

During the war an Interdepartmental Quarantine Commission, including the Armed Divisions and the United States Public Health Service, conducted a worldwide survey of the efficiency of current quarantine procedures. Magath (1945a, b) has recently reviewed the conclusions regarding modernization of quarantine regulations. The potential role of rapidly expanding aerial traffic was evaluated on the basis of past records. Despite the general belief that such traffic would greatly increase the hazard from quarantinable disease, "up to the present time there is little evidence to support such a conclusion". Only one case of mild smallpox has been known in the international air traffic of the world, and there is no evidence that an exotic vector of disease has ever become established in an area as a result of transportation by airplane. (Soper and Williams (1943) concluded that fast mailships were responsible for the introduction of *Anopheles gambiae* from Africa into Brazil in 1929 or 1930. However, five live adults found in Natal in 1943 were presumably brought in by airplane, though no breeding has been discovered since eradication of the species in 1940.) Anopheline mosquitoes have apparently not been implanted in any of the Pacific Islands previously free from them, despite extensive military air and sea traffic. Although disinsectization of planes has been primarily directed against mosquitoes and prevailing methods utilizing aerosol pyrethrum and DDT sprays are effective for them, accumulated evidence indicates that the greater danger lies in the possible introduction of agricultural pests (particularly as eggs or larvae in infested products) which require additional control measures.

The question of entomological quarantine of aircraft has thus been a subject of investigation for the comparatively short span of about fifteen years. Yet considerable data are already at hand to serve as guides for future developments. While disinsectization methods currently practiced have an efficiency that renders them both practical and valuable in meeting the problem, new and improved techniques are highly desirable and are being sought. The various aspects of this problem are under study by a Subcommittee of the Interdepartmental Pest Control Committee

(personal communication from G. L. Dunnahoo, Chief of the Foreign Quarantine Division, U.S.P.H.S.)

INTERNATIONAL AIR ROUTES AND VOLUME OF TRAFFIC

The American Aviation Air Traffic Guide for September, 1946, indicates that, at the present time, four American and three foreign companies have regularly scheduled passenger flights between foreign ports and the United States. Incoming flights total about 66 a day to all ports of entry, or over 24,000 a year. About 50 per cent of these enter Miami from the West Indies, Mexico, Central America, and South America, and another 22 per cent from the latter three areas into other southern ports (principally Brownsville, Texas; also San Antonio, El Paso, New Orleans, and Los Angeles). Eighteen per cent of extracontinental traffic enters New York from Bermuda, the West Indies, South America, Europe, and Africa, 8 per cent into Seattle from Alaska, and 2 per cent into San Francisco from the Pacific area via Hawaii. About 80 per cent of the scheduled flights (52 a day) come from the Caribbean area and South America, mostly into the southern ports of entry. Thirty-one flights a week from Europe and 2 a week from Africa enter New York, and 8 a week from Honolulu (including one originating in New Zealand) enter San Francisco.

For a more accurate conception of present day air traffic into the United States from foreign ports, there must be added many unscheduled commercial flights and non-commercial flights of military and private planes, arriving not only at the aforementioned ports but at other civilian and military terminals. Records from Brownsville indicate that about 30 per cent of incoming traffic falls into these categories. On this basis, the total number of planes entering the continental United States must approach some 35,000 a year, or an average of nearly a hundred a day. This is probably a conservative estimate, since statistics available to this Committee are far from complete. Since the end of the war, the decrease of international military traffic has been offset by constantly increasing commercial traffic. Miami currently receives about 1500 planes a month, simulating or exceeding the records of the busy closing months of the war.

The volume of international air traffic is expected to increase rapidly, including not only more frequent and faster passenger service, but a constantly growing use of cargo planes. Applications of American and foreign air transport companies are pending for the licensing of many new overseas routes, and the entire world will eventually be covered by a network of international airways comparable in comprehensiveness to the national routes already operated within the United States. Besides increasing traffic to ports of entry already mentioned, new terminals (*e.g.*, at Washington, Chicago, Detroit, and Houston) will undoubtedly become established. Longer flights will bring airplanes from South America, Africa, India, the Orient and the Pacific area directly into the United States by transoceanic and arctic routes.

Travel time from the Caribbean area to the United States is at present a matter of one to twelve hours, from more distant South American ports about 24 hours, from Europe some 16 hours, from Africa 48 hours, from Hawaii 15 hours, and from New Zealand 70 hours. With faster planes and more direct flights these time intervals will be substantially reduced, so that no spot on earth will be more than two days from the United States.

GEOGRAPHICAL DISTRIBUTION OF ANOPHELINES AND IMPORTANT MALARIA VECTORS

Of about 290 recognized species and varieties of *Anopheles*, only 12 occur in the United States and Canada. Sixty-two others are found in Mexico, the Caribbean area, and South America; 22 in Europe and North Africa; 85 in the rest of Africa; and 109 in Asia, the Philippines, and the Australasian region. Some 54 species and varieties are regarded as important vectors somewhere within their ranges. The United States has 2; Latin America 7; Europe and North Africa 8; the rest of Africa 10; Asia, the Philippines and Australasia 29.[2]

Since the bulk of our international air traffic at present is with Latin America (which has 7 important vectors among 62 species not already occurring in the United States), it may seem that the greatest danger of importation of exotic species lies in that quarter. But aeronautical proximity and an abundant anopheline fauna do not necessarily render an area the most potentially dangerous as a source for *significant* importation of exotic forms. From the standpoint of gross climatic conditions, the European and non-tropical areas elsewhere correspond more closely to the United States as a whole, and therefore may be more likely sources of species that could gain a foothold here. An evaluation of the potentialities of exotic species to become implanted might perhaps better be based upon isothermal or isophanal (Hopkins, 1938) considerations. However, such a multitude of factors conceivably determine the chances of survival and reproduction that it is difficult, if not impossible, to predict which species would be most apt to flourish if transplanted. These factors are outlined later in this report. An increase in air traffic between climatically similar areas, now separated by high natural barriers, may enable the realization of potentialities of temperate-zone species not possessed by species that are essentially tropical in habit.

REPORTS OF MOSQUITOES INTERCEPTED ON AIRPLANES AND RATE OF "IMPORTATION"

A few records of mosquitoes found on international airplanes entering the United States have been published (Griffitts and Griffitts, 1931; Griffitts, 1933; Welch, 1939; U. S. Public Health Service, 1937, 1945). With the exception of the 1945 list, these are all of specimens intercepted at Miami at various times (July 23–Sept. 12, 1931; November, 1937; Jan. 1–Dec. 31, 1938). They record a total of 569 planes inspected, of which 232 harbored 736 insects, including 87 mosquitoes (8 alive). Among these were one *Anopheles albimanus* (dead) and one *Aëdes aegypti;* the others were culicines of six identified species, none of which can be regarded as exotic in a strict sense.[3]

[2] Figures based upon listings in Russell, West, and Manwell (1946) and Russell, Rozeboom, and Stone (1943). A tabulation of the recognition characters of adult malaria vectors of the world (tarsal, palp, wing, and other diagnostic features) has been prepared and will be submitted if the Society wishes to publish it as an aid to airplane inspectors in the identification of intercepted specimens.

[3] In this report the term "exotic" is used only for species that are non-indigenous and have never been reported as breeding in Nature anywhere in the continental United States. Not included in this category are species (like *Anopheles albimanus*) which, while essentially tropical, do occur locally in restricted southern areas, evidently as a natural extension of their range.

(Twenty specimens of *Mansonia indubitans* were included, but recent investigations by Pratt (1945) and Chamberlain and Duffey (1945) indicate that this species exists in Florida and was collected in the larval stage there as early as 1931; it was formerly confused with *M. titillans.*) An unspecified number of other mosquitoes, including *Anopheles albimanus* and *pseudopunctipennis*, are mentioned as found in 1931 and 1932 by Griffitts (1933). The records through 1938 are also included in the world list of 227 kinds of insects found on aircraft given by Whitfield (1939) in his detailed analytical review of the subject.

The list published by the United States Public Health Service in its Annual Report for 1945 is of mosquitoes recovered on planes at Miami, Fla., Brownsville and Fort Worth, Texas, New Orleans, La., and San Juan, Puerto Rico, from July 1, 1944 to June 30, 1945. A total of 1418 mosquitoes (158 alive) were among 24,930 insects found on 12,367 aircraft. The majority of the mosquitoes (1339 specimens, 142 alive) were culicines, which included 21 identified species (two exotic) as follows: (Number alive/total number found, stated in parentheses; exotic species indicated by bold-face type.)

Aëdes: aegypti (0/9); *atlanticus* (0/1); *nigromaculis* (0/1); *scapularis* (0/1); *sollicitans* (6/22); *taeniorhynchus* (7/221); *thelcter* (0/1); undetermined species (0/14)
Aëdomyia squamipennis (0/3).
Culex: declarator (0/2); *nigripalpus* (0/2); *quinquefasciatus* (88/215); *salinarius* (0/14); *tarsalis* (5/7); (*Culex*) sp. (14/127); (*Melanoconion*) sp. (0/60).
Culiseta inornata (1/2).
Mansonia: ***humeralis*** (0/1); *titillans* (7/82); undetermined species (0/10).
Psorophora: ciliata (1/3); *confinnis* (11/517); *cyanescens* (1/3); *pygmaea* (0/1); *undetermined species* (0/5).
Uranotaenia lowii (0/1).
Culicidae species undetermined (1/14).

The anophelines listed (79 specimens, 16 alive) included 9 identified species (four exotic):

Anopheles: albimanus (10/34); *crucians* (0/19); ***grabhamii*** (0/1); ***maculipennis aztecus*** [?] (0/1); ***neomaculipalpus*** (0/1); ***pharoensis*** (0/1); *pseudopunctipennis* (2/4); *punctipennis* (1/1); *quadrimaculatus* (3/5); (*Nyssorhynchus*) sp. (0/4); undetermined species (0/8).

To obtain a better indication of the actual rate of transportation of exotic mosquitoes to the United States by airplanes, the records of interceptions at the quarantine stations of Miami, Brownsville, and New Orleans during the past two or three years were examined by one of the writers (A. M.) through the kindness of Drs. G. H. Bradley, A. W. Para, and G. J. Van Beeck of the United States Public Health Service. These records form only part of the cumulative data gathered by the Service, all of which must be comprehensively processed and analyzed before they can be published and substantial conclusions drawn. An unofficial analysis, however, revealed that the results of inspections of over 35,000 planes at the stations named, during two- or three-year periods (1943–1946), show trends that are fairly represented by the published report reviewed above. Most of the aircraft inspected were commercial

passenger planes entering the United States from the West Indies, Mexico, Central America, and South America; others were military planes from the same areas and also some from North and West Africa, Europe, and India. Additional specimens of some of the anophelines named above have been found, and also a few *Anopheles albitarsis* and one *A. walkeri.* Five species of exotic anophelines and 10 exotic culicines are included in the total of 50 species identified. Exotic species were represented by less than two percent of the specimens intercepted and by dead specimens only.

In terms of the average number of specimens per 100 airplanes, calculations based upon the published 1945 data provide infestation indices of 201.5 insects, 11.5 mosquitoes (1.3 alive), 0.64 anophelines (0.13 alive), 0.1 exotic mosquitoes (0 alive) and 0.03–0.06 exotic anophelines (0 alive). (The larger exotic anopheline index, 0.06, assumes the four unidentified specimens of *Nyssorhynchus* to be exotic.) Since these values are based upon the records of only one year, they can be regarded only as an indication of the relative numbers in each category. As such, however, they are in substantial agreement with the larger body of data examined and will serve our present purpose.

It is recognized that records of the sort on which these infestation rates are based are, at best, only approximations to the actual facts, since their compilation is bound to include a considerable degree of unavoidable error, both human and mechanical. Among these may be failure to detect all specimens present in the plane, the possible egress or ingress of living insects when doors or windows are opened (however briefly) after landing but before inspection is made, and misidentifications of battered or unfamiliar specimens. Finding insects on airplanes requires systematic and meticulous effort and is made difficult by the many hiding places afforded by the interior structure, furnishings, and upholstery. In practice, the search is made immediately after passengers and crew disembark, with doors and hatches closed. Movable objects in the cabin compartments are shaken to dislodge living insects and all surfaces are examined with the aid of a flashlight, sometimes before and always after spraying. The baggage compartment is similarly examined before and after unloading. Investigation indicates that not more than 10 percent of mosquitoes which gain access to an airplane are detected by the inspector. It should also be noted that insects listed as "alive" are not necessarily viable to the extent of being capable of reproduction, or even of finding suitable breeding places if they do get out of the plane. Despite these inevitable shortcomings, however, in the aggregate a large body of such data may be regarded as affording a fair indication of relative numbers and as providing minimal figures for a quantitative appraisal of potential importation.

It is of interest to speculate on the theoretical number of exotic mosquitoes which may be imported at the index rates given above. If the indices are considered as having an accuracy of 10 percent and are therefore increased ten-fold, possible rates of infestation per 100 planes would be 115 mosquitoes (13 alive), 6.4 anophelines (1.3 alive), and 1 exotic mosquito, including 0.3–0.6 exotic anophelines. At this rate a yearly traffic of 35,000 incoming planes would be expected to bring in some 350 exotic mosquitoes, of which about 100 to 200 might be anophelines not already recorded from the United States. If the proportion of living mosquitoes to total

mosquitoes (13:115, or 11.3 percent) is applied to these figures, the ten-fold indices suggest an importation rate of about 10 to 25 living exotic anophelines a year, *i.e.* in 35,000 planes. Actually no viable exotic anophelines have been discovered in over 35,000 planes during more than three years of inspection, perhaps due, in large part, to disinsectization. The potentialities of these hypothetical 10 to 25 living anophelines a year will be considered later.

Magath (1945a, b) states that records from tens of thousands of planes all over the world include only nine *Aëdes aegypti* (one alive) and nearly 300 *Anopheles gambiae* (10 alive). Collections in airplanes arriving in Brazil from Africa, during 1941 and the first quarter of 1942, include seven *gambiae*, two *Anopheles coustani*, and one *Aëdes aegypti* (Soper and Williams, 1943). The United States records examined included eight *aegypti* and no *gambiae*. Two of the five species of exotic *Anopheles* found (*albitarsis* and *pharoensis*) are proved malaria vectors of importance in some parts of their home ranges (South America and Africa, respectively). The most frequently encountered anopheline, *albimanus*, is an important vector in the Caribbean region, but it is already "common in southeast Texas in the Brownsville area and along the lower Rio Grande" (Matheson, 1944). In Florida, 131 adults were found at Key West in 1904 (perhaps the progeny of a single female brought by ship from Vera Cruz) but not again until 1943 at West Palm Beach (one dead female, probably of this species) and 1944 at Boca Raton (only one fourth-instar larva, possibly from a female imported by plane from Puerto Rico) (Mulrennan et al., 1945; Welch, 1945). The species may have been accidentally introduced a number of times into Florida without successful establishment. Pritchard et al. (1946) report the finding of another larva on Big Pine Key on January 13, 1946; they suggest that the species may be indigenous to the Florida Keys but that conditions enable it to maintain itself there "only in erratic and extremely limited numbers". With the exception of *pharoensis*, all exotic anophelines were found on planes from the Caribbean area and South America. *Pharoensis* was on a military plane from Africa. This species and an Indian culicine are the only Old World mosquitoes included in the reports that are not already present in the United States. Other exotic culicines found, including *Aëdomyia squamipennis* and *Mansonia humeralis*, are neotropical species.

The species of mosquitoes found most frequently on planes (*Aëdes taeniorhynchus*, *Culex quinquefasciatus*, and *Psorophora confinnis*) are already common in the United States, so that their only quarantine importance would lie in the possibility of disease-infected individuals (e.g. harboring encephalitis virus) being imported from foreign areas. A certain degree of correlation between the abundance of these and other species in planes and at the ports of entry suggests that some of those found in planes may even be of local origin and have entered at the time of inspection, especially when landings occurred during the mosquitoes' hours of flight. Careful observation at all ports used by the plane would be necessary to determine their actual origin.

Definite conclusions that can be reached on the basis of available reports are: (1) Mosquitoes do enter airplanes, the tendency to do so varying with the species, their flight habits, and their abundance in the vicinity of airports. (2) Live mosquitoes are occasionally found on planes after flight, though in small numbers (at least

after spraying). (3) The great majority of mosquitoes found in airplanes entering the United States are of species already established in this country. Whatever may have been the origin of the stowaways, they are of no direct concern from the standpoint of species-quarantine, though they may be in respect to the importation of disease. (4) It is evident that *Aëdes aegypti* seldom gains access to airplanes (as Magath, 1945a and b, has pointed out), and that exotic anophelines constitute the smallest portion of mosquitoes brought into the United States by aircraft (on the order of perhaps three to six specimens in every 1000 planes entering southern ports). *With present methods of disinsectization* only about 10 to 20 living exotic anophelines would be expected in every 30,000 planes, if the analyzed records are considered as having an accuracy of 10 percent. The potential significance of this is considered in the following section.

FACTORS INFLUENCING THE TRANSPORT OF MOSQUITOES BY AIRPLANE AND THE PROBABILITY OF THEIR ESTABLISHMENT IN NEW AREAS

The transport of mosquitoes by airplane is influenced by their abundance near airports and landing fields, their flight habits and tendency to enter man-made shelters, the accessibility and attractiveness of planes while on the ground, and the structure of the plane, particularly with regard to openings and protected spaces that may harbor insects. While the larger airports, with their wide unsheltered areas, generally are not hospitable to frail insects like mosquitoes, conditions may be favorable around the margins of landing fields and in hangars and other buildings. Many species have long flight ranges and wander extensively from their breeding places. The scarcity of the shelter-loving *Aëdes aegypti* on planes is probably due to its normally limited range of flight and questing habits, although it may breed in and around buildings near the aircraft. The abundance of strong-flying coastal species in planes reflects their prolific numbers around suitably situated fields, their migration from breeding places to seek food or shelter, and their success in gaining entrance to artificial structures. There is no evidence that mosquitoes enter while planes are in the air, even in open planes. The slipstream probably renders this impossible. The structure of the plane determines ease of ingress and the ability of mosquitoes to remain and survive. Modern planes afford little opportunity for insects to find sheltered places on the exterior, with the possible exception of recesses into which wheels are withdrawn. The fuselage spaces—particularly cabin and baggage compartments—are the places where insects are usually found. Spaces in the wings and around motors may provide entrances and suitable shelter, but Magath (1945b) states that very little insect debris is found in structural spaces outside the cabin. Cargo planes, with unfinished interiors and piles of freight, can be expected to provide abundant nooks adequately sheltered from air currents to permit insects to remain.

Even though mosquitoes may be transported by plane, practical significance of such transportation depends upon their ability to survive the trip and to become established in a new environment.

It is apparent from the records that living insects are found on planes at the termination of flights, though most recovered insects are dead, due either to the use of insect sprays or to other causes. Griffitts (1931, 1933) released 100 stained *Aëdes aegypti*

in ten planes and recovered 22 of them alive after flights of 1250 miles taking ten hours or more, despite landings that involved opening doors and hatches for passengers and baggage. Other series of experiments, with larger numbers of mosquitoes and planes, demonstrated conclusively that this species could survive on planes at least as long as 79 hours, remained in them when overnight and other intermediate stops were made, and took blood meals during flight. It is not uncommon to see house flies in passenger planes. Factors affecting insect-survival during transport include time, temperature, humidity, protection from strong air currents, presence of insecticidal substances, and probably vibration of resting surfaces. Insects are largely indifferent to changes in air pressure, and conditions comfortable for man generally also are favorable to insects. More rapid trips and air-conditioned cabins can be expected to increase the chance of survival of mosquitoes in planes. However the important question of the effect of vibration both on survival and true viability and fecundity of mosquito stowaways requires investigation. The efficacy of insecticidal sprays or residues, and the thoroughness and frequency of their application will, of course, be a primary determinant of insect survival.

Implantation (*i.e.*, successful establishment) of an exotic species in a new environment does not depend only upon the survival of immigrant specimens during the flight and their arrival in a viable state. Many obstacles and hazards must be overcome by the new arrivals before they can produce descendents which can in turn survive in sufficient numbers to reproduce and enable the species to attain a firm foothold in its new abode. The stowaways must be able to leave the plane and find a suitable environment in which to survive, feed, and produce offspring. This implies reasonable proximity of suitable breeding areas at the port of entry, for mosquitoes in the form of marshes or other types of water attractive to the species. While the barrenness of larger airfields may impose a considerable initial obstacle to disembarking mosquitoes, winds may blow them to more hospitable marginal areas. The season and weather at the time of arrival must be favorable, and acceptable host animals must be present to provide blood meals. Unless the species is imported in unusually (and improbably) large numbers, only fecundated females are potent as primary settlers. Airplanes normally do not afford opportunity for the effective importation of eggs, larvae, or pupae of mosquitoes, though ships in the past have and sometimes may still do so. If the first batch of eggs does hatch and produce a new generation of adults, these must be numerous and concentrated enough to permit the sexes to find each other and mate, since parthenogenesis is unknown in mosquitoes. In many species, swarming of males is an essential condition for mating. A relatively small number of individuals of a new species are, furthermore, at a disadvantage in the struggle for existence. Predators, parasites, diseases, adverse climatic conditions, natural accidents, and competition with the more numerous native species all decrease the chances for effective survival of the pioneer generations. If suitable breeding areas, food, and micro-climatic conditions are available and the species survives local changes in weather and season, a colony may succeed in becoming established and form a nucleus for subsequent spread. Species adaptability and habits, as well as chance, would determine the survival and reproduction of the earlier generations. To the adversities imposed by the dilution factor—small numbers

which may become too scattered to mate and reproduce repeatedly—must be added the possibility of absorption of the early generations by cross-breeding with closely related native species or varieties (e.g., *A. quadrimaculatus* and *A. maculipennis freeborni* have been hybridized at the Columbia S. C., laboratory).

In the face of all these factors which militate against the establishment of a species in a new area, it would be remarkable if the hypothetical 10 to 25 specimens a year of exotic anophelines, postulated above, should succeed in initiating an invasion of the United States. But in biology, the remarkable is far from uncommon. Such implantations, though rare, have occurred. The most impressive instance is, of course, the invasion of Brazil by *A. gambiae.* However it may have been imported, its habits and species vigor were such that it found and took advantage of congenial conditions in Brazil, where the climate is apparently enough like that of Africa to enable the species to flourish despite natural hazards and obstacles. The finding of the exotic *Psorophora mexicana* in larval and adult collections in the vicinity of Brownsville (U.S.P.H.S. Ann. Rep., 1944) may be an example that the same thing "can happen here", given an adaptable species and sufficient importation. On the other hand, the failure of transplanted species to survive for more than a generation or two in a new area has also been observed. The failure of *albimanus* to become established, or at least abundant, in Florida has already been mentioned. Magath (1945b) mentions another example, in that imported *Aëdes vigilax* persisted in the Fiji Islands for only one season. Russell *et al.* (1946) cite several instances of spread and implantation of Old World anophelines in new regions by trucks, trains, and river boats. It is, therefore, conceivable that some readily adaptable species like *A. gambiae* and the Indian *culcifacies* may constitute a remote threat to the United States through airplane importation. Because this country has temperate and subtropical climates, species from Europe, the Mediterranean area, and parts of the Orient and of Australia may be even more likely to find suitable conditions here if they are carried over the natural barriers of distance and oceans by plane. Our southern ports of entry, where winters are comparatively mild, would seem to afford the best opportunities for a new species to gain an effective foothold.

The fact that most species of mosquitoes have more or less definitely restricted ranges, sometimes because of natural barriers obvious to us, but often for obscure and undiscovered reasons, indicates that extension of range is not a simple spreading from established foci. Even heavy and constant transportation by vehicles, trains, ships, and aircraft, may be only slowly or not at all effective in disseminating species beyond their known habitats. The airplane, due to its speed, may, indeed, provide the means for a species to pass over barriers otherwise insurmountable, but there is still no certain evidence that it has done so, either intra- or internationally. That anophelines have not yet been found on new Pacific islands despite voluminous and, for the most part, unquarantined water and air traffic between them and infested areas is another indication that the transplantation of mosquitoes does not occur as readily as one might imagine.

Nevertheless, however slight the apparent danger, sound public health practice dictates that reasonable precautions be taken to minimize the possibility of introducing exotic mosquitoes into the United States and its insular possessions. Current quaran-

tine practices and efforts to increase their efficiency deserve commendation and support. Their purpose is to guard not only against the probable, but also against the possible. The possibility of implantation of new vectors of disease by airplane traffic cannot be denied.

POTENTIALITIES OF TRANSPORTATION OF MALARIA VECTORS

While exotic anophelines infected with malaria might conceivably enter airplanes and be transported to the United States, such an event seems a very remote possibility and of little or no practical significance if it did occur. Since a relatively small proportion of potential vectors are actually infected or infective in an endemic area, the chance of such an individual being among the few mosquitoes that do enter planes is negligible. Even if an infective specimen were tranported, the most harm it could do would be to infect one or two persons on the plane or soon after disembarking. If it survived to reproduce, the malaria parasite would die with the parent mosquito. Human carriers are the only likely means of disseminating new strains of malaria parasites in a region, and the chances are preponderantly greater for such infections to originate in the endemic area rather than as a result of the bite of an emigrant mosquito.

If uninfected specimens of highly efficient vector species were to be imported, they would be of possible significance in our malaria problem only if they succeeded in becoming established and numerous in the United States. Not only would they first have to overcome the obstacles already discussed, but their efficiency as vectors here would be dependent upon all the factors involved in malaria transmission by any species, *viz.* availability of plasmodia, susceptibility, breeding, feeding, and flight habits, tendency to enter houses, length of life, etc. The new environment encountered here by an exotic species may present different conditions than that prevailing in regions where the species is an important vector and tend to alter its efficiency as a transmitter. For example, *A. albimanus* is apparently less susceptible to infection under laboratory conditions in the United States than in its natural habitat (Young *et al.*, 1946). Prediction of the probable importance of a transplanted species is therefore impossible. That immigrant species may, however, be more efficient than native vectors is again illustrated by the record of *gambiae* in Brazil.

Adequate surveillance of mosquito breeding in our malarious areas should result in detection and control of introduced species before they could become important factors in our malaria problems.

PRECAUTIONARY AND PREVENTIVE MEASURES

Preventive measures to guard against the implantation of exotic insects by international airplane traffic comprise the following categories: (1) Measures to prevent the entry of insects into aircraft at foreign ports (airport insect control and insect-proofing). (2) Measures to destroy and intercept insects that have gained entrance into aircraft (disinsectization and inspection). (3) Entomological surveillance around airports of entry to detect promptly incipient establishment of exotic insects that have evaded interception (routine insect surveys and control in and around international airports).

Discussion of preventive measures will be limited to those primarily directed against mosquitoes. While effective to some extent against other types of insects, they are inadequate safeguards for insects of different habit, particularly potential agricultural pests that may be transported concealed in baggage or cargo in the form of eggs, young, or adults in plant products or other materials.

The concept of "sanitary aerodromes" in regard to insect vectors of disease arose as an essential part of yellow fever quarantine procedure in endemic areas and areas exposed to risk (anti-amaryl aerodromes). The principle applies equally as a safeguard against mosquitoes and other pests that may inadvertently become stowaways in airplanes, though in practice it may encounter severe limitations. Methods effective in controlling the breeding of a domestic and short-flighted mosquito like *Aëdes aegypti* are inadequate to cope with species which develop in less restricted breeding places, such as ground water, and have long flight ranges. Nevertheless, every effort should be made to maintain effective control measures on and around airports to diminish the number of adult mosquitoes which may find their way into airplanes. Mosquito-proofing of buildings and of aircraft, by screening wherever practical and by residual sprays or insecticidal coatings, can do much to lessen the entry and survival of flying insects about and in planes on the field or in hangars. Outdoor area-disinsectization by the use of smoke aerosols might be applicable on airfields if conditions should require it. Regional mosquito-sanitation requires competent supervision and intelligent engineering practices to avoid inadvertent production of man-made breeding places. Preventive measures of this sort are of quarantine value for all stations and ports of entry, as well as ports of origin. This is now recognized by commercial air transport companies as well as by governmental public health services and is practiced to varying degrees of completeness through the combined influence of quarantine regulations and intelligent cooperation. Promulgation of knowledge of the need, value, and methods of such sanitation is included in the responsibilities of public health and quarantine agencies, as well as inspection and enforcement in areas subject to control.

Since ideally complete control is unattainable on airports, mosquitoes can and do enter grounded aircraft through doors, hatches, and other openings. This requires disinsectization measures to further minimize the transportation of viable mosquitoes to other ports. The exterior of planes offer so little shelter for insects that outside spraying is unnecessary, unless it be in protected spaces in landing-gear recesses. The most practical means thus far developed to destroy such stowaways is the use of insecticidal sprays in the closed airplane preceding, during, or at the termination of flight (for a discussion of the time of spraying, see Magath 1945a, b). Hand-operated or mechanical spraying apparatus may be used, and various insecticides have been tested, but at present pyrethrum-aerosols are preferred and have been adopted for routine spraying of commercial and military aircraft by the U.S. Public Health Service (Parran, 1944). Federal regulations (Quarantine Laws and Regulations . . . Applicable to International Aerial Navigation, 1942) give in detail the manner of inspecting and disinsecting aircraft. These are now under revision and Dr. G. L. Dunnahoo, Chief of the Foreign Quarantine Division, (personal communication) summarizes current practice as follows:

Essentially regulations call for a killing dose of insecticide to be introduced in all compartments of an airplane not later than thirty minutes prior to landing in the United States or Territorial ports under control of the United States. There are specified exceptions to this rule. On landing of the airplane a sanitary inspector checks the sworn statements as to the time and quantities of material used in disinsectization and makes a brief inspection for the purpose of determining whether or not the statements are correct. If the inspector has cause to believe that the plane has not been properly disinsectized, he may keep the aircraft closed and treat all enclosed spaces with the required dosage before the passengers or crew are permitted to disembark. If the inspector's search reveals that no free-flying forms of insect remain alive, he permits passengers and crew to disembark and may close the plane for another treatment with insecticide. In Honolulu we have made special arrangements with Department of Agriculture representatives whereby they introduce a very large quantity of insecticide (approximately four times the Public Health Service dosage) as the measure for the destruction of insects of agricultural significance.

While admittedly not perfect, these methods are known to effect a high rate of kill (the best more than 90 per cent) and are hence regarded as worthwhile procedures. Effective spraying requires adequate dosage and proper application (thoroughness and sufficient holding time). Although air transport companies are willing to cooperate by using sprays during flight, operating personnel may not always be as thorough in spraying as efficacy requires, either through carelessness, indifference, or regard for the ill-advised objections of passengers. It is difficult to overcome such human failings.

Investigations are under way to develop more efficient techniques. Increase in the size and complexity of planes can be expected to render more difficult adequate disinsectization and inspection. While residual DDT or other synthetic sprays, repeated at intervals, offer promising means of combatting insect stowaways, they have not yet been generally introduced because of the possible harmful effects of the solvents on electrical insulation, connections, and instruments essential to the safe operation of intricate modern planes. It is suggested that insecticidal paints, coatings, or harmless sprays might be developed, upholstery could be impregnated, and structural changes in the planes may be feasible that, while conforming with sound design, would facilitate disinsectization or reduce insect harborage. "Piping" planes with conduits for insect sprays operated by push-buttons, or by automatic devices activated by some essential flight process when taking off or landing, also offer possible ways to offset human carelessness and enable more adequate treatment of all spaces in the plane. The added weight involved in such devices constitutes one of the principle difficulties in their development and adoption.

Routine mosquito control and surveillance around airports is regarded by the Public Health Service as an essential second line of defense, inasmuch as there can be no absolute certainty that insects are not brought in by planes. Chances are thereby materially decreased for a new species to become established or to escape detection during the early period when eradication is relatively easier.

SUMMARY AND CONCLUSIONS

The possibility of aeronautical transportation of mosquito vectors of disease has been appreciated for about twenty years and international quarantine regulations of

1933 and 1944 include measures to combat the danger. Fifteen years of investigation and experience has thrown considerable light upon the potentialities of mosquitoes to be carried and implanted by aircraft and upon the effectiveness of control methods.

It is estimated that airplanes now enter the United States from foreign ports at a probable rate of about 35,000 a year. Some 80 per cent of these are from the West Indies and Latin America, the majority coming into southern ports of entry. Regular traffic from the Pacific area and Africa (where more than 50 per cent of malaria-transmitting species of *Anopheles* occur) is still limited but can be expected to increase progressively. Scheduled flight times from all parts of the world are short enough to enable stowaway mosquitoes to arrive alive in the United States.

An analysis of the records of inspections at Miami, Brownsville, and New Orleans during the past three years indicates that about 45 per cent of inspected planes harbored insects and about 6 per cent bore mosquitoes. Several thousand mosquitoes were found, including 50 identified species. Less than two per cent of the specimens consisted of 15 recognized exotic species. Only a few were exotic anophelines, representing one African, one Mexican, and three neotropical species, and none of these was alive when found. If recorded recoveries (with present methods of disinsectization and inspection) are regarded as representing 10 per cent of the mosquitoes actually present, conformable published data of one year provide transportation-rate indices per 100 planes of about one exotic mosquito and 0.3–0.6 exotic anophelines; if 11 per cent of these were alive (the ratio for all mosquitoes found), these rates indicate a hypothetical maximum of 10 to 20 viable exotic specimens of *Anopheles* in 30,000 planes.

The chances for a yearly importation of this magnitude to result in implantation of new anopheline species in the United States seem slight, in view of the many factors that can be expected to militate against their effective establishment. The possibility of inadvertently importing new strains of malaria in mosquitoes is infinitesimal and of no quarantine concern.

Despite the theoretically small chance of significant importation of exotic species, prudence and past experience require that quarantine precautions be maintained by mosquito control around airports, disinsectization of planes with improved methods, and routine surveillance of exposed areas to detect incipient breeding of imported anophelines.

Southern ports of entry, with more favorable year-round climatic conditions, are regarded as offering the most likely invasion points. It seems probable that exotic species from non-tropical areas may find conditions in the United States more suitable than predominantly tropical forms and may therefore have greater potentialities to become established. The importance of non-indigenous species as malaria vectors in a new environment is unpredictable and subject to many influences.

The fear of accidental introduction of exotic species of anophelines has sometimes been exaggerated more than the degree of real danger seems to warrant. With the precautions currently employed, implantation of new malaria vectors in the United States is a potential but not an acute problem.

RESUMEN Y CONCLUSIONES

La posibilidad del transporte aéreo de mosquitos vectores de enfermedades se ha observado desde hace case 20 años y las reglamentaciones internacionales de cuarentena de 1933 y 1944 dan medidas para evitar el peligro. Quince años de investigación y experiencia suministran considerables datos sobre la potencialidad de los mosquitos para ser transportados por avión lo mismo que la efectividad de los métodos de control.

Se calcula que en la actualidad entran a los Estados Unidos, de puertos extranjeros, casi 35.000 aviones por año. Un 80 porciento provienen de las Indias occidentales y Latino América, llegando la mayoría a los puertos del sur. El tráfico regular del área del Pacífico y Africa (donde existe más del 50 por ciento de los Anopheles vectores de malaria) está aún limitado pero se debe esperar su progresivo incremento. Los itinerarios de vuelo en todas partes del mundo son suficientemente cortos para permitir que mosquitos ocultos lleguen vivos a los Estados Unidos.

Un análisis de los registros de inspecciones en Miami, Brownsville, y Nueva Orleans durante los últimos tres años indica quecerca del 45 por ciento de los aviones inspeccionados albergaban insectos, y casi un 6 por ciento de los aviones portaban mosquitos. Se encontraron muchos millares de mosquitos, comprendiendo 50 especies identificadas. Menos del 2 por ciento de los ejemplares era de 15 especies exóticas reconocidas. Solo unos pocos eran Anophelinos exóticos, representadas una especie Africana, una Mexicana, y tres especies neotropicales, ninguno de los cuales fué hallado vivo. Si las capturas registradas (con los actuales métodos de desinsectización e inspección) se aceptan como un 10% de los mosquitos presentes actualmente, los datos publicados de un año suministran índices de transporte, por cada 100 aviones de casi un mosquito exótico y 0.3–0.6 de Anophelinos exóticos; si 11 de éstos estuvieran vivos (la proporción para todos los mosquitos encontrados), estas tasas indicarían un máximum hipotético de 10 a 20 especímenes exóticos viables de *Anopheles* en 30.000 aviones.

Las probabilidades de una importación anual de ésta magnitud para que de élla resulte la implatación de una especie nueva de Anophelino en los Estados Unidos parece muy remota, en vista de los innumerables factores que actúan en contra del establecimiento efectivo de élla.

A pesar de la poca posibilidad de importación de especies exóticas, la prudencia y la experiencia pasadas exigen que se mantenga y tenga precauciones de cuarentena y un control de mosquitos alrededor de los aeropuertos, desinsectización de los aviones con métodos perfeccionados, como también la supervigilancia de rutina en las áreas expuestas para descubrir los criaderos incipientes de Anophelinos importados.

Los puertos de entrada del sur, con condiciones climáticas más favorables durante todo el año, se consideran como los puntosmás apropiados para una invasión. Es posible que especies exóticas de áreas no tropicales puedan encontrar mejores condiciones en los Esta dos Unidos que las formas tropicales predominantes 6 así tener mayor capacidad para establecerse.

La importancia de especies no nativas como vectores de malaria en un nuevo ambiente es imprevisible y está sujeta a muchas contingencias.

El temor a la introducción accidental de especies exóticas de Anophelinos se ha exagerado en muchas ocasiones mas allá del peligro real que parece tener. Con las

precauciones empleadas corrientemente la implatación de vectores nuevos de malaria, en los Estados Unidos, es un problema potencial y no agudo.

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TRANSMISSION OF *PLASMODIUM GALLINACEUM* BY *ANOPHELES QUADRIMACULATUS*[1]

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The successful transmission of *Plasmodium gallinaceum* from chick to chick by *Anopheles quadrimaculatus*, including transmission through the act of biting, is described in this note. According to reviews by Beltran (1941, 1942) and by Cantrell and Jordan (1945), 27 species of mosquitoes have been found capable of serving as hosts to *P. gallinaceum*, including 7 species added by the latter authors. No anopheline has thus far been reported as a vector of this avian malaria parasite.

Very few instances of development of any avian plasmodium in anopheline mosquitoes have been described. Mayne (1928) found oocysts and a few sporozoites of *P. relictum* in *A. subpictus* which had bitten infected birds Lucena (1938) found a single oocyst of *P. cathemerium* in *A. strodei*, according to the review by Hurlbut and Hewitt (1941). Coggeshall (1940) reported development of *P. lophurae* in *A. quadrimaculatus* to the oocyst stage, with 12 infected stomachs in 25 dissections, and a maximum of 40 cysts per stomach. Hurlbut and Hewitt (1941) reported oocysts of *P. lophurae* in 7 out of 29 dissections, and sporozoites in 1 set of salivary glands. None of these authors reported transmission of any plasmodium from bird to bird by an anopheline.

During April, 1947, we allowed 2 separate lots of *A. quadrimaculatus* to feed on chicks whose blood smears showed gametocytes of *P. gallinaceum*. All the mosquitoes were insectary-reared, from a colony that has been maintained many years in the laboratory. The *P. gallinaceum* is from the 8A strain, obtained in 1944 from Dr. G. R. Coatney, and maintained in this laboratory by alternating chick and *Aedes aegypti* passage.

Findings in mosquitoes were as follows:

(a) From the first lot, oocysts were found on 3 stomachs out of 10 dissections, on the 10th day after biting. (Mosquitoes were maintained at 74°–78°F. and 70 per cent relative humidity.) Two stomachs contained at least 50 cysts each; one had a single cyst.

(b) In the second lot, 53 dissections were done on the 12th day, and 8 stomachs were found to contain oocysts. Two had more than 100 cysts each, 4 had more than 50, one had 15, and one had 2. Many cysts were packed with sporozoites, numbers of which had been liberated by rupture of the cysts during examination. Two

[1] We are indebted to Miss Lois Seamans of the Department of Health and Safety, Tennessee Valley Authority, for some of these mosquitoes, furnished from the insectary at the College of Medicine, University of Tennessee, which were pooled with our own. All are from the same parent colony.

We are also indebted to Misses Nell Coleman, Mary P. Coode, and Agnes Laine for the examinations of blood films made from chicks used in this study.

stomachs, and the saline in which they had been placed for examination, were aspirated into tuberculin syringes and inoculated into separate chicks, intramuscularly. One of these chicks showed patent infection on the 9th day.

Approximately 40 mosquitoes in this lot were not dissected. On the 14th day, they were divided into 3 groups, and those in each group were allowed to engorge on a single chick. Of the 3 chicks thus bitten, 1 developed patent infection on the 9th day.

The mosquitoes after this feeding, were immediately triturated in serum-saline mixture (equal parts normal chick serum and 0.9 per cent sodium chloride solution), about 3 cc of the mixture being used for the entire lot. The suspension, after brief centrifuging at about 100 r.p.m., was inoculated into 3 chicks, subcutaneously. One of these chicks was found to have a patent infection on the 12th day.

Other workers have noted the significance attaching to the development of avian plasmodia in anophelines. Mayne (1928), discussing his own findings, referred to them as "evidence—warranting the assumption that one need be more circumspect in the incrimination of species of anophelines as natural carriers of malaria." Hurlbut and Hewitt (1941) say of their observations that "the finding reported here tends to invalidate the assumption that all oocysts and sporozoites which may be found [in *A. quadrimaculatus*] are those of human malaria."

The experiments described herein, demonstrating the completion of the exogenous cycle of an avian plasmodium in an anopheline, emphasize more than ever the importance of caution in interpreting results when mosquito dissections are done in the field in connection with investigations of human malaria.

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THE METABOLISM OF CINCHONINE IN DOGS AND IN MAN

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In a paper on the relative rates of absorption of quinine and some other common cinchona alkaloids from isolated intestinal loops of dogs, Cornatzer and Andrews (1944) reported that in one animal cinchonine dihydrochloride showed a rate of absorption as much as 24 per cent higher than did quinine dihydrochloride from the same loops and under the same conditions as regards time, concentration, etc. Other animals, with similar loops, showed differences that were less marked between the speed of absorption of cinchonine and that of quinine, but in all cases the cinchonine disappeared more rapidly from the intestinal loop than did the quinine. At about the same time Hiatt (1944) reported his findings on the plasma concentrations of these alkaloids resulting in man from their administration by mouth as the free bases. Hiatt's results showed that whereas the plasma levels of quinine, quinidine, and cinchonidine attained were comparable, only very low concentrations of cinchonine could be detected. Thus, in man, the behavior of the two optical isomers, cinchonine and cinchonidine, was markedly different. On the other hand, Hiatt and Quinn (1945) found little difference between the distribution of these four alkaloids in plasma and various tissues of dogs infused intravenously with solutions of the same; and Seeler, Dusenbery, and Malanga (1943) found about the same schizonticidal activity against *P. lophurae* in Pekin ducklings on the part of all four, in spite of a number of conflicting reports which they quote from the earlier literature.

In order to reconcile the apparently divergent results of Cornatzer and Andrews with those of Hiatt we must recognize that the rate of absorption of the drug from the small intestine into the blood stream and its subsequent rates of metabolic destruction and urinary excretion may be, and probably are, quite independent. Since, in the opinion of most workers, the active anti-schizontazoidal agent is some metabolic product of the alkaloid, variations in the degree and speed of this metabolic breakdown may be quite significant.

There is much less likelihood of there being any great difference between the rates of absorption in humans and dogs of any given alkaloid since absorption results of a number of foodstuffs in experimental animals have been found valid for man. Differences in the rate of absorption are much less likely to be specific to the species than differences in metabolic rate. Furthermore, the fact that Hiatt administered the alkaloids as the free bases whereas Cornatzer and Andrews used the much more soluble dihydrochlorides might, as indicated by Andrews and Cornatzer (1944), also have influenced the results.

However, it is only in man that the behavior of cinchonine appears markedly different from that of the other three common cinchona alkaloids; and even in man there is no clear evidence of any sharp difference in antimalarial activity, as is evi-

denced by the successful use of the mixture "Totaquina," which usually contains large amounts of cinchonine. It is the purpose of the present paper to attempt to clarify this situation by presenting data bearing on the comparative blood levels and urinary excretions of cinchonine attained in a dog and in a human subject. In both cases, comparisons were made with quinine and cinchonidine.

METHODS

Commericial samples of some of the cinchona alkaloids are notoriously impure. For this reason we have thought it necessary to use only the dihydrochlorides of these bases after careful purification. This is particularly true of cinchonine. This alkaloid is usually contaminated with variable amounts of quinine and other cinchona bases (Allen, 1929), and since such contaminants could vitiate the comparisons desired, we used a portion of the sample purified as described by Andrews (1942) for use in optical activity measurements. The commercial sample from which this was prepared contained originally about 12 per cent quinine, and twenty-six successive ether extractions were required to attain a complete removal of the latter with consequent constancy of the solubility and optical activity of the cinchonine. From this purified sample of the base the dihydrochloride was prepared and used in the following experiments. The other alkaloid dihydrochlorides used were purified by repeated recrystallizations.

The dog experiments were carried out using an animal with an isolated intestinal loop, the one designated as "Dog III" in the above mentioned paper by Cornatzer and Andrews (1944). This animal had always showed smaller differences between the rates of absorption of cinchonine, cinchonidine, and quinine from its loop than did Dog I, but the disappearance of the first named was always the most rapid. Comparisons made with this animal over a space of about two years showed consistently that its ability to absorb cinchonine was, in terms of absolute percentage absorption, from 12 to 20 per cent higher than its ability to absorb quinine. The doses of the alkaloid were introduced into the loop at a level of 20 mg. per kilo body weight, expressed as anhydrous sulfate, by the technique previously described, and left for 60-minute periods. Blood and urine samples were taken at the beginning of the experiment and at subsequent periods of 1, 2, 4, 6, 12, and 24 hours.

In the human experiments, the dose was taken by mouth, and blood and urine samples were collected at similar intervals and analyzed by the method of Kyker, Webb, and Andrews (1941). Values for cinchonidine and cinchonine were determined by the modification described by Kyker and Lewis (1945).

RESULTS

The data collected from the dog with an isolated intestinal loop are recorded in Table 1. In this case there is obviously no significant difference between the levels attained by all three alkaloids in the blood stream, but the quinine figures show the lowest percentages of excretion as the unchanged alkaloid of any of the three. The 3.7 per cent excreted unchanged is in accord with the data of Andrews and Anderson (1943) collected from other dogs with intestinal loops. We may conclude that, as

regards the dog, neither cinchonine nor cinchonidine is metabolized to the extent of quinine but that all three alkaloids produce about the same curves of blood concentration. This finding, in turn, confirms our earlier data on their relative rates of disappearance from the intestinal loops.

The data in Table 2, however, confirm the sharp distinction between the behavior of cinchonine in man and that of either its optical isomer, cinchnidine, or of quinine. We find that the concentrations of cinchonine attained in blood are all under one milligram per liter, a range which is hardly above the limit of error of the analytical method employed. We thus confirm the results of Hiatt (1944) with human subjects, both as regards the wide difference between the blood levels of quinine and cinchonine and also as regards the intermediate position of cinchonidine. To the writers there appears to be little likelihood that the sharp difference between dogs and human subjects as regards cinchonine is ascribable to a difference in degree of absorption between the two species, and it is evident that more efficient removal of the cinchonine by the kidneys cannot be the explanation since the total percentage of the dose excreted is far below that of quinine and cinchonidine. If, therefore, we may assume reasonable validity of the results obtained by the loop technique

TABLE 1

Levels of Blood Concentration and Urinary Excretion of Cinchonine, Cinchonidine, and Quinine Resulting from Their Administration as Dihydrochlorides in the Isolated Intestinal Loop of a Dog

Wt. of dog, 10.3 kg. Dose equal to 20.0 mg. anhydrous quinine sulfate per kg. body weight All figures expressed as free base.

TIME	CINCHONINE			CINCHONIDINE			QUININE		
	Blood conc.	Amount excreted in urine per period of time indicated	Total excretion in urine from beginning of experiment	Blood conc.	Amount excreted in urine per period of time indicated	Total excretion in urine from beginning of experiment	Blood conc.	Amount excreted in urine per period of time indicated	Total excretion in urine from beginning of experiment
hrs.	*mg. per liter*	*mg.*	*mg.*	*mg. per liter*	*mg.*	*mg.*	*mg. per liter*	*mg.*	*mg.*
1	3.45	2.80	2.80	4.30	2.10	2.10	3.18	0.53	0.53
2	2.40	4.90	7.70	3.90	2.59	4.69	2.77	0.72	1.25
4	1.50	4.80	12.50				2.23	1.59	2.84
6	1.32	3.60	16.10	2.14	15.50	20.19	1.17	0.58	3.42
12	0.81	6.70	22.8	0.96	13.80	33.99	0.85	0.66	4.08
24	0.66	2.40	25.2	0.88	1.65	35.64	0.66	0.82	4.90
Amt. base administered	178.9 mg.			178.9 mg.			178.9 mg.		
Amt. base absorbed	154.9 mg.			148.9 mg.			131.2 mg.		
Per cent base absorbed	86.6			83.3			73.4		
Per cent base excreted of that absorbed	16.2			23.9			3.7		

and similarity between dogs and man as regards their ability to absorb these drugs, it seems that the only alternative is to assume that the difference lies in the rôle of metabolic destruction. The next step in the testing of this hypothesis would obviously be the injection of doses of these three dihydrochlorides into human subjects with subsequent determination of the curves of blood concentration and urinary excretion. It is of particular interest to note the great contrast indicated by the present data in the metabolic behavior of two alkaloids (cinchonine and cinchonidine) which differ from each other only in the configuration of two out of their four optically active carbon atoms.

TABLE 2

Levels of Blood Concentration and Urinary Excretion of Cinchonine, Cinchonidine, and Quinine Resulting from Their Administration as Dihydrochlorides by Mouth to a Human Subject

Wt. of subject, 69.1 kg. Dose equal to 10 mg. free base per kg. body weight. All figures expressed as free base.

TIME	CINCHONINE			CINCHONIDINE			QUININE		
	Blood conc.	Amount excreted in urine per period of time indicated	Total excretion in urine from beginning of experiment	Blood conc.	Amount excreted in urine per period of time indicated	Total excretion in urine from beginning of experiment	Blood conc.	Amount excreted in urine per period of time indicated	Total excretion in urine from beginning of experiment
hrs.	*mg. per liter*	*mg.*	*mg.*	*mg. per liter*	*mg.*	*mg.*	*mg. per liter*	*mg.*	*mg.*
1.5	0.72	10.14	10.14	2.17	10.45	10.45	4.16	14.42	14.42
3	0.76	4.50	14.64	1.80	22.0	32.45	3.42	16.68	31.10
6	0.30	36.50	51.14	1.35	47.45	79.90	2.68	41.78	72.88
12	0.82	8.40	59.64	0.66	54.50	134.40	1.20	51.07	123.95
24		1.70	61.34		35.04	169.44		39.35	163.30
Per cent base excreted............		8.8			24.5			23.6	

CONCLUSIONS

1. Data are presented confirming our earlier conclusion that in dogs with isolated intestinal loops both cinchonidine and cinchonine dihydrochlorides are absorbed somewhat more rapidly than is quinine dihydro chloride. However, the blood con centrations of these three alkaloids are of aboutthe same order over a 24-hour period-after administration of the dose. Carefully purified samples of all three alkaloids were used.

2. Doses of the same three alkaloids taken by a human subject by mouth showed normal blood levels for cinchonidine and quinine, but very low levels, hardly outside the error of the method, for cinchonine. These findings confirm those of Hiatt.

3. These data indicate that cinchonine is metabolized much more rapidly than cinchonidine and quinine in man and also much more rapidly in man than in the dog. In the latter these distinctions do not exist.

RESUMEN

1. Se dan pruebas que confirman nuestra primera conclusión de que en perros con un asa intestinal aislada tánto el biclorhidrato de cinconidina como el como el biclorhidrato de cinconina son absorbidos más rápidamente que el biclorhidrato de quinina.

Sin embargo, las concentraciones sanguíneas de éstos tres alcaloides son casi las mismas después de 24 horas de administración de la dosis. Se emplearon muestras cuidadosamente purificadas de los tres alcaloides.

2. Dosis de los mismos alcaloides suministradas a un individuo por vía oral mostraron concentraciones sanguíneas normales en elcaso de la cinconidina y la quinina, pero muy bajos niveles, mucho mayores que el error del método, para la cinconina. Estos hallazgos confirman los de Hiatt.

3. Estos datos indican que en el hombre la cinconina se metaboliza mucho más rapidamente que la cinconidina y la quinina y, más aúnque en perro. En éste no existen tales diferencias.

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